# GEOLOGY OF THE COASTLINE BETWEEN POINT GAMMON AND MONOMOY POINT, CAPE COD MASSACHUSETTS

by

**NEWTON·E·CHUTE**

PREPARED UNDER A COOPERATIVE PROJECT FOR GEOLOGIC INVESTIGATIONS IN THE COMMONWEALTH OF MASSACHUSETTS

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J. W. Beal, Commissioner.

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W. C. Mendenhall, Director.

Special Paper 1

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# Introduction

This report is based on a study of the geological features of the south shore of Cape Cod between Hyannis and Chatham, made at the request of R. K. Hale, Director of Waterways, Massachusetts Department of Public Works. Its purpose is to present a geologic background as well as certain geologic data pertinent to problems of coast control.

The report is composed of two parts: the first consists of a general description of the geologic history and origin of the materials that make up the Cape area as a whole; the second presents a more detailed description of the geologic features of the south shore, between Hyannis and Chatham. Twenty-nine sections of the shoreline between these points and the salient features of these sections are discussed in the text. The locations of these sections are indicated on the accompanying map.

Two weeks were spent in the field studying the area between Hyannis and Chatham. Information concerning the geology of the other parts of Cape Cod and adjoining regions was obtained during reconnaissance trips and from published reports.

# Part 1

## Summary of the Geologic History of Cape Cod

The geologic history of a region is interpreted from the character of its geologic formations. The scientific basis for the determination of the relative ages of the many known geologic formations is too involved for discussion here, and would not be materially pertinent to problems of coast control. Briefly it may be stated that geologic time has been classified into successive periods ranging from the time of deposition of the oldest known rocks of the earth's crust to that of the deposits now in process of accumulation, such as the beach sands along the present shores. The following table presents the major divisions of the geologic time scale.

### Eras and Periods of Geologic Time

| Era | Period | |
|---|---|---|
| Cenozoic | Quaternary | Recent<br>Pleistocene ("Glacial Epoch") |
| | Tertiary | Each period has numerous subdivisions recognizable in different regions. |
| Mesozoic | Cretaceous<br>Jurassic<br>Triassic | |
| Paleozoic | Carboniferous<br>Devonian<br>Silurian<br>Ordovician<br>Cambrian | |

(Pre-Paleozoic time is divided into numerous periods and doubtless constitutes the major part of geologic time).

In no area are formations of all periods present, so that recognition of the ages of the formations in a given area is dependent upon correlation of its strata with those of other areas.

Only Pleistocene and later deposits are exposed at the surface on Cape Cod. Because the older rocks are completely concealed, the pre-Pleistocene history of the Cape must be inferred from rock exposures in the adjoining region. The Pleistocene deposits of the Cape region and adjacent areas are largely of glacial origin; that is, deposited directly or indirectly by ice sheets that covered a large part of North America during the Pleistocene epoch, or by the melt waters from these sheets. Because deposits of glacial derivation characterize the greater part of the Pleistocene history, this time is also frequently described as the "Glacial Period".

For convenience in this discussion the rocks of eastern Massachusetts are divided into three major groups according to age and character: the pre-Cretaceous group, the Cretaceous and Tertiary group, and the post-Tertiary group. The pre-Cretaceous group of rocks is the oldest. It consists of a variety of igneous rocks (consolidated from a molten state), sedimentary rocks (deposited by ocean, lake, or river waters), and metamorphic rocks (profoundly altered by recrystallization). These rocks differ greatly in age, but none of them is believed to be less than a hundred million years old. The rocks of this group now exposed at the surface were once deeply buried under other rocks, and variously deformed and metamorphosed by earth stresses. Except for the glacial and recent deposits most of the rocks exposed in eastern Massachusetts belong to

this group, and it is very probable that these rocks extend eastward under the glacial deposits of Cape Cod. During the long interval of time between the formation of the rocks of the pre-Cretaceous group and the deposition of the rocks of the Cretaceous and Tertiary group the surface,once mountainous, was eroded hundreds, and perhaps even thousands of feet to form a plain-like lowland. In the Cape Cod region this interval of erosion was brought to a close in the Cretaceous period when the ocean submerged the eastern margin of the continent.

The Cretaceous and Tertiary rocks were deposited in this marginal sea on the eroded surface of the older group. The Cretaceous and Tertiary formations consist of gently inclined beds of unconsolidated and poorly consolidated sands, silts, clays, and marls. It is not known how far the ocean waters extended inland but representatives of this group are now exposed on Marthas Vineyard and Elizabeth Islands on the south side of Cape Cod, and near Marshfield on the north side.

South of New York this group forms the coastal plain of the States bordering the Atlantic Ocean. Probably New England had a similar coastal plain until erosion removed the northwestern part of it and subsidence, in comparatively recent time, submerged the remainder. The former existence of such a coastal plain in eastern Massachusetts is inferred by exposures of Cretaceous and Tertiary deposits on Long Island and in the vicinity of Cape Cod, and by the character and configuration of Georges Bank and the bottom of the Gulf of Maine. Exposures of these deposits both to north and to

south of Cape Cod make it very probable that they also underlie the Cape.

After millions of years the ocean waters withdrew from the edge of the continent, thus terminating the deposition of the Cretaceous-Tertiary sediments and exposing them to dissection by erosion. Because of the difference in degree of consolidation of the different beds of this group and their low inclination the edges of those beds most resistant to erosion were left as broad asymmetrical ridges, called cuestas. Long Island is believed to be built upon such a ridge. Georges Bank is a submerged ridge probably composed of these formations and the southern part of Cape Cod may be built on a continuation of that ridge.

The Pleistocene glacial and later deposits constitute the third and youngest, or post-Tertiary, group. About a million years ago glaciers commenced to form in Canada and to extend southward into the United States. Good evidence of four major glacial stages has been found in the northern part of the Mississippi River valley. Each glacial stage lasted for thousands of years and was separated from the others by even longer intervals, during which the glaciers melted away and the climate became even warmer than it is in that region today. The number of ice sheets that invaded New England is much more difficult to determine. Evidence of at least two and perhaps three different glacial advances appear on Marthas Vineyard and Nantucket.

The center of accumulation of the ice sheets that covered New England was on the Labrador Peninsula. As the ice moved southward

and southeastward across New England it picked up loose surface materials and scoured the bedrock, but it apparently did not greatly modify the pre-glacial topography. The load carried by the ice consisted of rock fragments of all sizes from rock flour to blocks tens of feet in length. Some of the material was transported a long distance but most of it was carried only a few miles or a few tens of miles before it was deposited.

Part of the rock debris carried by a glacier is dropped as a mixture of unsorted materials, called till, and part is picked up, moved, sized, and deposited by melt waters to form more or less sorted and stratified deposits of gravel, sand, silt, and clay. The till and waterlaid material are known collectively as glacial drift. Some till is deposited under the ice when the ice is moving, but most is probably deposited as the ice melts away. When the edge of an ice sheet melts back about as fast as the ice is moving forward the ice front remains nearly stationary. The longer this condition lasts the larger becomes the knobby ridge-like deposit of drift, called a moraine, that melts out and accumulates along the edge of the ice. Such a moraine may range from a fraction of a mile to several miles in width and usually includes some waterlaid gravels and sands. The prominent range of hills on Cape Cod along the east side of Buzzards Bay and the south side of Cape Cod Bay is a moraine of this origin.

The waterlaid deposits of glacial derivation are of several types. Some are lake-bottom or delta deposits and others are stream-channel deposits. The most important of these deposits found on

Cape Cod is the outwash plain, a broad essentially continuous plain of sand and gravel deposited at the front of the ice sheet by numerous shifting streams of melt water. On Cape Cod a pitted outwash plain covers the surface between the moraine mentioned above and Nantucket Sound.

Little is known concerning the maximum extent of the earliest ice sheets in New England. One of the last sheets reached at least as far south as Marthas Vineyard and Nantucket and probably a considerable distance into the Atlantic on the east. As the ice retreated its margin became lobate. One lobe appears to have occupied Cape Cod Bay, another probably lay to the east separated from the former by the forearm of the Cape, and a third lay to the west in the vicinity of Buzzards Bay. A large moraine was heaped up on Cape Cod at the margins of the lobes during a prolonged halt in the retreat of the glacier. This moraine consists of a range from 1 to 4 miles wide of boulder-strewn hills composed of till, sand and gravel. It extends from Woods Hole northward along the east side of Buzzards Bay to the Cape Cod Canal, where it turns and is continuous eastward parallel to the north shore of the Cape through Barnstable to the Atlantic Ocean east of Orleans. The range of hills that extends northward from the canal to the vicinity of Plymouth is thought to be an interlobate extension of this moraine.

The forearm of the Cape from the vicinity of Orleans northward to East Harbor or Pilgrim Lake consists of a series of pitted outwash sand and gravel plains that rise to different altitudes and, therefore, are presumed to have been deposited at somewhat different

times. Because the surface of each of these plains slopes toward the west, it is thought that they were formed by streams that flowed westward from an ice lobe that lay to the east.

The bedded sands, clays, and gravels exposed in places under these outwash sands and gravels, for example in the cliffs near Highland Light, have been tentatively assigned by Woodworth and Wigglesworth(4)* to older glacial and interglacial stages. Certain isolated hills along the south shore of the Cape also are composed of the older glacial deposits. These hills rose above the general level and were never covered by the sands and gravels of the younger outwash plain. Such hills are located at Point Gammon, Hyannisport, Centreville, Falmouth Heights, and a few other places.

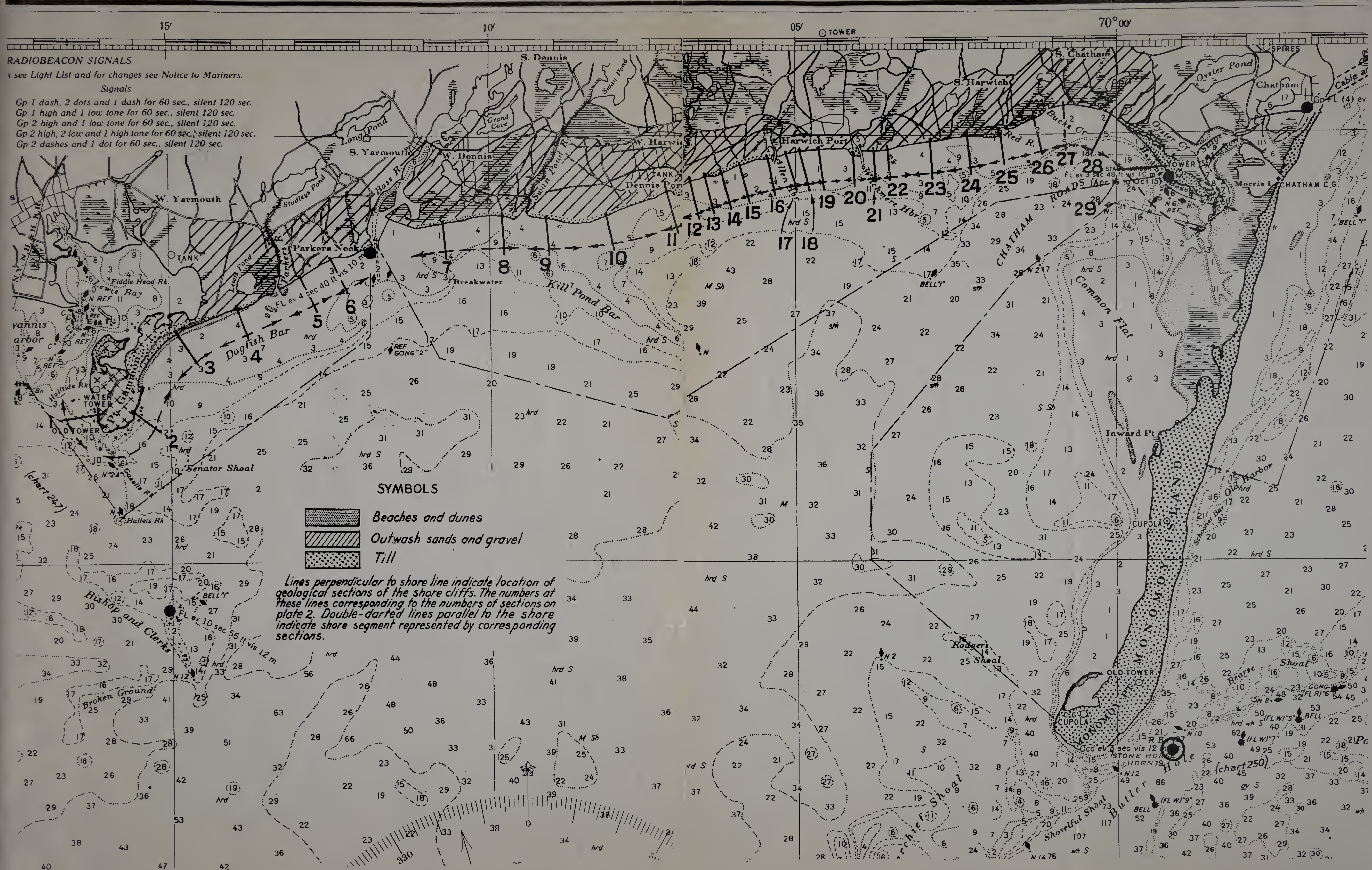
The total thickness of the glacial deposits on Cape Cod is not known. Borings and excavations have not reached the pre-Pleistocene rocks. Woodworth and Wigglesworth(4) state that the deepest well on the Cape was drilled at Provincetown in 1905 to a depth of 420 or 450 feet without passing through the entire thickness of the glacial deposits. More recently, Ewing(1) has made a seismic profile from Falmouth southward, and has determined that the eroded surface of the oldest group of rocks lies at a depth of about 295 feet at Woods Hole. Some of this thickness, however, may consist of unconsolidated Cretaceous and Tertiary deposits. Although the evidence is very meager, it is probable that the glacial and interglacial deposits of Cape Cod range from one hundred to several hundred feet in thickness. Cape Cod apparently owes much if not most of its position,

*Numbers refer to bibliography at end of report.

shape, and height above sea level to the glacial deposits.

Since the last glacial ice melted away some swamp, lake, and stream deposits have accumulated and the area of the Cape has been reduced by wave erosion. Monomoy Point, Nauset Beach, Hardings Beach, the provincelands at the north end of the Cape, and the other spits, bars, and beaches have been constructed from the debris of this erosion.

How long the sea level has been near its present position in the Cape Cod region is not certainly known. Some geologists believe that sea level has not shifted appreciably for two thousand years or more. During that time the east side of the forearm of the Cape is estimated to have been cut back as much as two and one-half miles. The other shores of the Cape also have retreated, but to lesser amounts, because of their greater protection from erosion.



## SYMBOLS

▩ Beaches and dunes

▨ Outwash sands and gravel

░ Till

Lines perpendicular to shore line indicate location of geological sections of the shore cliffs. The numbers at these lines corresponding to the numbers of sections on plate 2. Double-darted lines parallel to the shore indicate shore segment represented by corresponding sections.

## Part 2

## Geology of the Coastline between Point Gammon and Monomoy Point

### Formations Exposed

The sequence of formations exposed between Hyannis and Chatham, south of highway #28 is as follows:

4. Dune sand
3. Outwash sands and gravels
2. Till
1. Sands with interstratified silts (oldest)

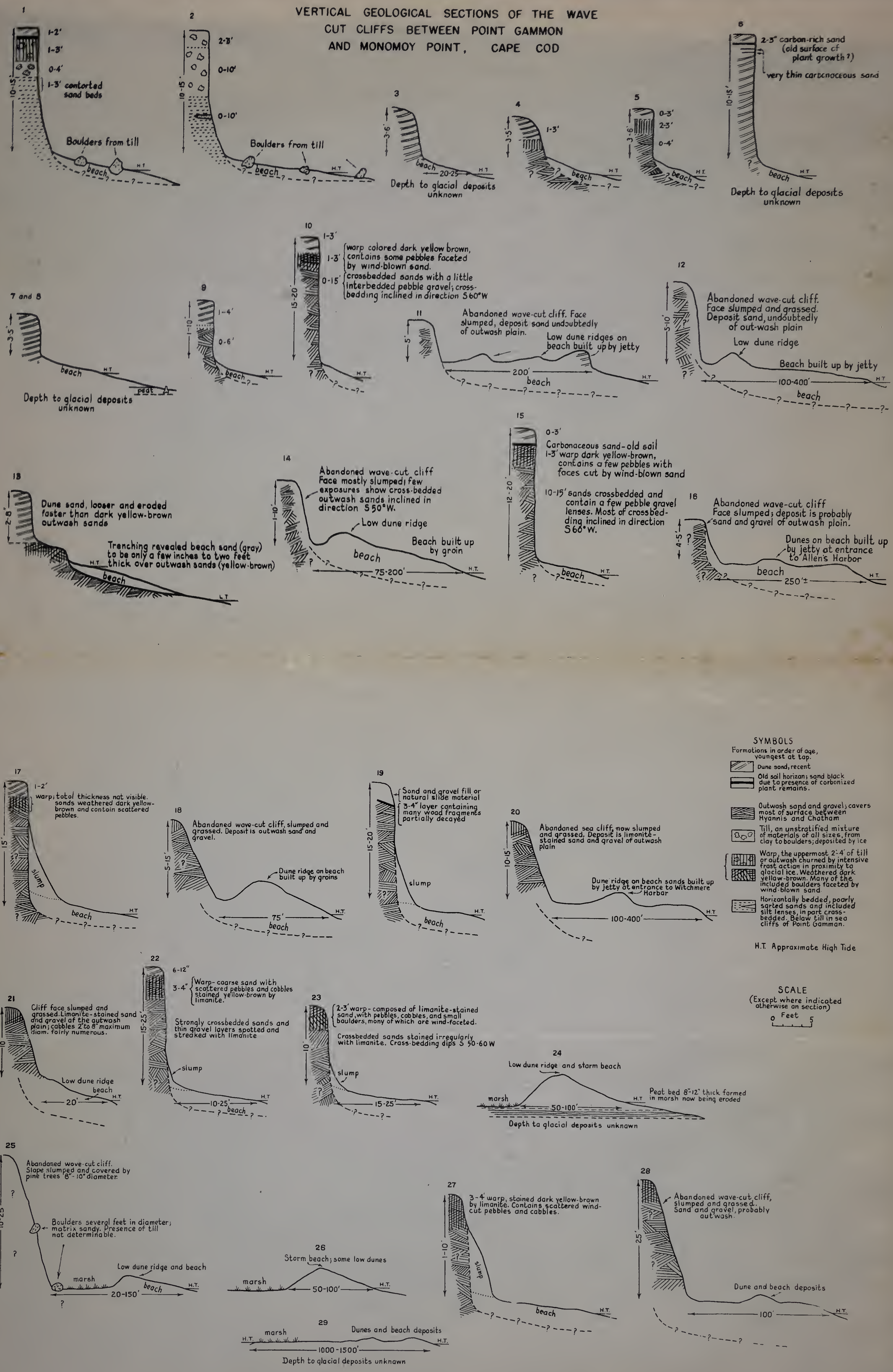
The accompanying geologic sections (plate 2) of the wave-cut cliffs between Point Gammon and Monomoy Point illustrate the occurrence of these formations along the shoreline. The location of each section and the portion of the shoreline that each section represents are indicated on the plan map, plate 1.

### Description of Formations

Sands with Interstratified Silts.--The sands with interstratified silts and the overlying till crop out on Point Gammon. Except for a few small sand pits, the sands and silts can be observed only in the shore cliffs. The total thickness of the formation is unknown, as not more than 15 feet of the upper part is exposed. The visible portion of the formation is mostly buff-colored, horizontally bedded coarse sand containing scattered pebbles and cobbles. In the sands are interbedded lenses of buff- to blue-colored clayey silts that range from a few inches to a few feet in thickness. Some of the silt layers are poorly sorted, as is evident from the pres-

# PLATE 2

## VERTICAL GEOLOGICAL SECTIONS OF THE WAVE CUT CLIFFS BETWEEN POINT GAMMON AND MONOMOY POINT, CAPE COD


1
1-2'
1-3'
0-4'
1-3' contorted sand beds
10-15'
Boulders from till
beach
H.T.
2
2-3'
0-10'
0-10'
10-15'
Boulders from till
beach
H.T.
3
3-6'
beach
20-25
H.T
Depth to glacial deposits unknown
4
3-5'
1-3'
beach
H.T
5
3-6'
0-3'
2-3'
0-4'
beach
H.T
6
2-3" carbon-rich sand (old surface of plant growth ?)
very thin carbonaceous sand
10-15'
beach
H.T
Depth to glacial deposits unknown
7 and 8
3-5'
beach
H.T
peat
Depth to glacial deposits unknown
9
1-10'
1-4'
0-6'
beach
H.T
10
1-3'
1-3' warp colored dark yellow brown, contains some pebbles faceted by wind-blown sand.
0-15' crossbedded sands with a little interbedded pebble gravel; cross-bedding inclined in direction S60°W
15-20'
H.T
11
5'
Abandoned wave-cut cliff. Face slumped, deposit sand undoubtedly of outwash plain.
Low dune ridges on beach built up by jetty
200'
beach
H.T
12
5-10'
Abandoned wave-cut cliff. Face slumped and grassed. Deposit sand, undoubtedly of out-wash plain
Low dune ridge
Beach built up by jetty
100-400'
beach
H.T
13
2-8'
Dune sand, looser and eroded faster than dark yellow-brown outwash sands
Trenching revealed beach sand (gray) to be only a few inches to two feet thick over outwash sands (yellow-brown)
H.T.
beach
L.T.
14
1-10'
Abandoned wave-cut cliff Face mostly slumped; few exposures show cross-bedded outwash sands inclined in direction S 50°W.
Low dune ridge
beach
Beach built up by groin
75-200'
H.T.
15
12-20'
0-3'
Carbonaceous sand-old soil
1-3' warp dark yellow-brown, contains a few pebbles with faces cut by wind-blown sand
10-15' sands crossbedded and contain a few pebble gravel lenses. Most of crossbedding inclined in direction S60°W.
beach
H.T.
16
4-5'
Abandoned wave-cut cliff Face slumped; deposit is probably sand and gravel of outwash plain.
Dunes on beach built up by jetty at entrance to Allen's Harbor
beach
250'±
H.T
17
1-2'
warp; total thickness not visible. sands weathered dark yellow-brown and contain scattered pebbles.
15'
slump
beach
H.T
18
5-15'
Abandoned wave-cut cliff, slumped and grassed. Deposit is outwash sand and gravel.
Dune ridge on beach built up by groins
75'
beach
H.T.
19
Sand and gravel fill or natural slide material
3-4" layer containing many wood fragments partially decayed
15-20'
slump
beach
H.T.
20
10-15'
Abandoned sea cliff, now slumped and grassed. Deposit is limonite-stained sand and gravel of outwash plain
Dune ridge on beach sands built up by jetty at entrance to Witchmere Harbar
100-400'
H.T
SYMBOLS
Formations in order of age, youngest at top.
Dune sand, recent
Old soil horizon; sand black due to presence of carbonized plant remains.
Outwash sand and gravel; covers most of surface between Hyannis and Chatham
Till, an unstratified mixture of materials of all sizes, from clay to boulders; deposited by ice
Warp, the uppermost 2'-4' of till or outwash churned by intensive frost action in proximity to glacial ice. Weathered dark yellow-brown. Many of the included boulders faceted by wind-blown sand.
Horizontally bedded, poorly sorted sands and included silt lenses, in part cross-bedded. Below till in sea cliffs of Point Gammon.
H.T. Approximate High Tide
21
10'
Cliff face slumped and grassed. Limonite-stained sand and gravel of the outwash plain; cobbles 2" to 8" maximum diam. fairly numerous.
Low dune ridge
beach
20'
H.T.
22
15-25'
6-12"
3-4" Warp-coarse sand with scattered pebbles and cobbles stained yellow-brown by limonite.
Strongly crossbedded sands and thin gravel layers spotted and streaked with limonite
slump
10-25'
beach
H.T
23
10'
2-3' warp-composed of limonite-stained sand, with pebbles, cobbles, and small boulders, many of which are wind-faceted.
Crossbedded sands stained irregularly with limonite. Cross-bedding dips S 50-60 W
slump
15-25'
H.T.
SCALE
(Except where indicated otherwise on section)
0 Feet 5
24
Low dune ridge and storm beach
marsh
50-100'
H.T
Peat bed 8"-12" thick formed in marsh now being eroded
Depth to glacial deposits unknown
25
10-25'
Abandoned wave-cut cliff. Slope slumped and covered by pine trees 8"-10" diameter.
Boulders several feet in diameter; matrix sandy. Presence of till not determinable.
marsh
Low dune ridge and beach
beach
20-150'
H.T.
26
Storm beach; some low dunes
marsh
50-100'
H.T.
27
1-10'
3-4' warp; stained dark yellow-brown by limonite. Contains scattered wind-cut pebbles and cobbles.
slump
beach
H.T.
28
25'
Abandoned wave-cut cliff, slumped and grassed. Sand and gravel, probably outwash.
Dune and beach deposits
100'
H.T.
29
H.T.
marsh
Dunes and beach deposits
H.T.
1000-1500'
Depth to glacial deposits unknown

ence of scattered granules and pebbles. The small folds in the sands and silts probably owe their origin to the drag of the ice sheet that deposited the overlying till.

Yellowish-brown stains of iron oxide produced by weathering are visible in the exposed portion of the deposit, but there is no indication that protracted weathering occurred between the deposition of these sands and of the overlying till.

The wave-cut cliffs on the north side of Stage Harbor, Chatham, expose sands and silts that are similar in character, bedding, structure, and general appearance to those at Point Gammon and may belong to the same formation.

Till.--The till overlying the interbedded sands and silts covers part of the surface of Point Gammon (see sections 1 and 2). It is from three to five feet thick in most exposures, but in a few places the thickness exceeds 5 feet. Boulders as much as 20 feet in maximum diameter are scattered through the clayey matrix of the till and may be seen in profusion along the shore and over the till surface of the Point. All of the till is weathered and has a buff to brownish color. Many of the included pebbles and cobbles are so thoroughly weathered, even at a depth of several feet below the surface, that they crumble readily under the blow of a hammer.

The upper part of the till, to a maximum depth of four feet, has been much disturbed by frost action. Where the till is thin this frost-heaved layer may include the full thickness of the till. Many of the boulders and cobbles in this portion of the till show facets carved by wind-blown sand. These facets could have been carved only

when the boulders were exposed at the surface, and, inasmuch as many of them are now in the lower part of the frost-heaved layer, it is clear that the frost action caused a churning of the till. Because this till is more weathered than many other till deposits in Massachusetts it is believed that it may be an older till. It may have been deposited either prior to the last stage of glaciation or during an early subdivision of the last stage and overridden by a readvance of the ice. In the area under discussion exposures of this till are known only on Point Gammon. The boulders and clays on the north side of Oyster Pond, Chatham, may belong to till of this age, but their relations are so obscure that no definite conclusions concerning their age could be made during the present study.

Outwash Sands and Gravels.--The till and the underlying sands and silts already discussed cover a relatively small portion of the surface of the area. Most of the surface between Hyannis and Chatham village consists of cross-bedded sands with some interbedded pebble and cobble gravels (see sections). Woodworth and Wigglesworth(4) divide the areas covered by these sands and gravels into the "Chatham Plain" to the east of the Herring River and the "Falmouth Plain" to the west, and assigned different ages to them. However, the writer has concluded that the sands and gravels at the surface between Hyannis and Chatham are all of the same age and origin, for the following reasons:

1) The degree of weathering appears to be the same throughout the area. The upper two to five feet of the sands and gravels are weathered to a dark yellow brown color owing to the formation of the

iron oxide, limonite. Limonite staining persists in the deepest sections observed but diminishes downward.

2) The frost-heaved layer, which averages about three feet in thickness, is equally developed over the whole area under consideration. Likewise, pebbles and cobbles in it show similar degrees of faceting by wind-blown sand and a similar degree of weathering of these facets.

3) All the sands and gravels are similarly cross-bedded and most of the cross-bedding observed in the wave-cut cliffs from Point Gammon to Chatham village is inclined toward the southwest (S. 50° - 60° W.), indicating a common northeast source. This conclusion is substantiated by the fact that the amount and coarseness of the gravel in the sands in the wave-cut cliffs increases from west to east.

4) Although there is greater topographic relief east of Harwichport than there is to the west the change in the relief is gradual. The surface of the outwash plain is higher east of Harwichport because that area is nearer the head of, and hence higher on, the outwash fan.

5) Throughout this area the outwash plain is pitted by kettleholes and large ice-block holes, formed by the melting of ice blocks that were remnants of the last ice sheet that covered the area. The kettleholes mark the sites of small ice blocks that were completely covered by the flood of sand and gravel of the outwash plain. The larger ice blocks were formed by blocks of ice which, because of their greater thickness, were probably surrounded but not covered by the sands and gravels. There has been very little valley cutting in

post-glacial times so that, except for the drainways, the abundant depressions in the sand plain are entirely due to the former presence of these ice blocks.

6) The surface of the outwash plain is creased by many valleys or drainways that trend southwest and south. Some of these are submerged in their lower reaches and form estuaries, some contain streams, such as Bass River, Swan Pond River, Herring River, and some are dry because they lie entirely above the ground water level. These valleys do not appear to have been formed by the streams that now occupy them. They were formed probably soon after the construction of the outwash plain, at a time when the normal runoff was greatly augmented by melt water from the ice blocks. When followed to their source the drainways are found to head in large ice-block holes or groups of smaller kettleholes. The striking southwesterly orientation of most of the drainways between Bass River and Chatham is believed by the writer to be due to the southwesterly slope of the original surface of the outwash plain.

Drainway valleys are similarly developed through the whole area between Hyannis and Chatham. Moreover, Bass River valley and Herring River valley pass through both the Falmouth and Chatham plains (as delimited by Woodworth and Wigglesworth)(4) without topographic change. This would not be expected unless these plains were of the same age and origin.

Sand Dunes.--Low sand dunes border much of the shore, particularly between Point Gammon and Harwichport (see sections). They form an interrupted belt of knobby hills and ridges up to one-

quarter mile wide that are easily distinguishable from the outwash sands and gravels by the light gray color of the dune sand and the shapes of the dunes. Much of the inland surface of the outwash plain is covered by a few inches of leached gray sand that in part may have been deposited by wind. Hills veneered with this sand may resemble dunes but the presence of the yellow outwash sand at shallow depth proves their true character.

The dunes have migrated inland with the shoreline so that those now visible are of recent origin. The warp on the outwash plain was formed and a thin soil, now full of carbonized plant fragments, developed before the dune sand accumulated. The source of the dune sand is chiefly the beach. At present the dunes in this area, exclusive of those on Monomoy Point and on the enlarged beaches, appear not to be migrating. Pine trees from 8 to 10 inches in diameter are growing on the dunes, and although a few older, partly buried trees may be seen, the dunes appear to have changed very little since the younger pine trees started to grow.

The surface of Monomoy Point consists entirely of beach, dune, and marsh deposits. Most of the sand has come from erosion of the east side of the Cape. Although the Point is being extended in places, erosion is causing the eastern shore to migrate westward at about the same rate as the eastern shore of the Cape to the north. Sand dunes are distributed over the Point but the largest and most continuous dunes border the shores. The dunes along the eastern shore move westward as the shore is cut back. This is clearly shown by old telephone poles that were at one time back from the shore but

are now near the wave-cut cliff and almost completely buried by the shore dunes.

## Influence of Materials on Rate of Wave Erosion

Between Hyannis and Chatham village the waves are acting on loose outwash sand and gravel deposits, beach deposits, sand dunes, and peat beds. These deposits differ somewhat in resistance to wave attack, but all of them offer only slight resistance. Dune sands are most easily eroded because of their greater looseness. Yellow outwash sands and gravels are slightly cemented by iron oxide, but not sufficiently to prevent them from being shovelled easily; hence they are little more resistant than the dune sands. Thick deposits of peat,even at the level of wave action,are very resistant to erosion, but along Cape Cod the peat visible in the littoral zone (that is, the zone between high and low tides) is in one or two layers that are too thin and of too small horizontal extent to retard erosion appreciably. Peat beds are found only in front of swamp areas now undergoing wave erosion. Till is more resistant than the other materials, but in the area between Hyannis and Chatham there is so little of it at the level of wave attack that it is not of much consequence in retarding shore erosion.

The till that covers Point Gammon is tough and compact, but in most places it lies above the zone of wave action. The underlying sands and silts, however, are in the zone of direct attack (see sections 1 and 2), and are so loose as not to be able to stand very long in vertical cliffs without slumping. Point Gammon is particu-

larly exposed to storm waves although it is partly protected by shoals and boulders. The retarded erosion of the Point, in spite of its exposed position, is apparently due to the presence of the till which is relatively hard and resistant and has shed many large boulders onto the shore. The configuration of the surface of the Point suggests that in the past, in sections of the Point now eroded, the till stood at a lower altitude. At that time, therefore, wave erosion must have been less effective than now because the waves broke against the resistant till. Without this shore defense Point Gammon would probably be undergoing more rapid erosion now.

Groins help in retarding wave erosion on Point Gammon but they are least effective near the end of the Point where the shore drift[1] begins. At the end of the Point most of the sand for the beaches is derived from the adjacent cliffs. Near the tip of the Point groins have not been very effective in holding this small supply of sand and need to be augmented by riprap or sea walls. Groins should be increasingly effective away from the tip of the Point. This is indicated by the fact that from a position about three-quarters of a mile north of the tip of the Point towards Lewis Bay the accumulation of sand is so thick that the beach has been built up and enlarged naturally.

Opposite most of the larger marshes a layer of peat about a foot thick, and in places tree stumps, are exposed on the beach between high- and low-tide levels. The peat was originally formed in

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[1] As used herein "shore drift" refers to currents along the shore mostly in a general shoreward direction from the breakers. Such drift can exist below lowest tide and hence is not exactly equivalent to "littoral drift" in the strict geologic sense.

marshes inland from the beach, and affords evidence of the advance of the shoreline upon the land. Although the peat and associated muck usually form a tough layer from 8 to 15 inches thick over the beach and resist erosion more than the adjacent sands, the areas of peat are too small to be of much influence in retarding wave erosion. It is evident, therefore, that wherever waves reach them the glacial and post-glacial deposits undergo rapid erosion.

## Beaches

The beaches represent temporary accumulations of debris in excess of that which could be removed by the waves. The prevailing direction of sand drift between Point Gammon and Monomoy Point is from west to east, as is clearly shown by the heavy accumulations of sand on the west sides of the jetties and groins and by shore erosion on the east sides. This prevailing eastward shore drift appears to be due chiefly to wave action caused by westerly winds.

The beach sands rest on the wave-cut platform and extend from the foot of the wave-cut cliff, or, where the shore is low, from the inland extremity of the storm beach, to a position between high and low tide levels (see sections). The width of the beach varies with the intensity of the wave action and the quantity of sand available. The beach is widened when the shore drift contributes more sand than the waves can remove.

When a shoreline is left undisturbed it is straightened by wave erosion. Points and promontories are cut back and beaches and bars are built across bays and marshes. The glacial materials on Cape Cod are easily eroded, and the shoreline between Point Gammon and Monomoy Point has been sufficiently straightened to permit continuous shore drift of sands between them whenever the works of man do not interfere.

The construction of jetties and groins has resulted in the disruption of the equilibrium established by natural processes. Results of this are clearly evident along the shore today. The groins

have definitely retarded the removal of the sand, have caused the beaches to be built up where they are located, and have accordingly diminished the rate of shore erosion without entirely stopping the movement of sand. The jetties, on the other hand, are causing more marked changes. For example, the large jetty on the west side of the mouth of Witchmere Harbor is stopping all the sand that moves along the shore. Consequently, the beach on the west side of the jetty is being built out so that near the jetty it is now about 400 feet wide. This beach extends with diminishing width for about a mile to the westward. There is little doubt that the jetty will continue to trap sand and build out the beach farther and farther until the sand can pass around the end of the jetty. The trapping of sand on the windward sides of the jetties results in excessive erosion on the leeward or east side. Where no sand is contributed by shore drift to partly replace that removed by wave action the beach is soon depleted and the land undergoes accelerated erosion for as much as a mile east of the longer jetties.

The source of the sand in the beaches is chiefly the land within reach of the waves, because the streams do not appear to contribute very much sand to the strand. As nearly as can be judged by inspection, very little of the beach sand comes from west of Point Gammon; in fact, there is a division in the shore drift on the Point itself. This division occurs at the southern tip of the Point where the drift is northward toward Lewis Bay on the west side of the Point and northeastward on the east side. It appears, therefore, that Point Gammon represents the westernmost limit for the source

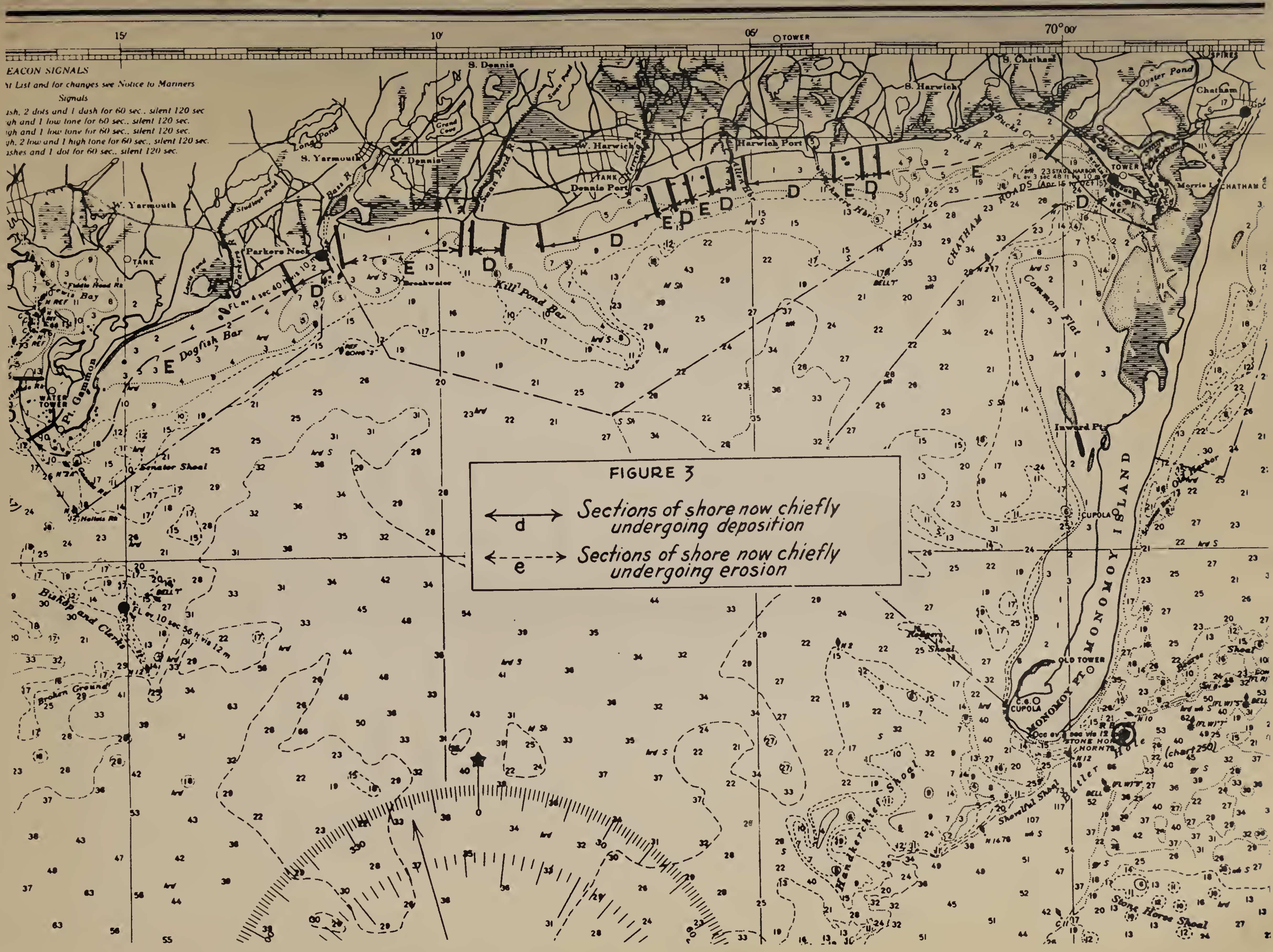EACON SIGNALS
Sections of shore now chiefly undergoing deposition
d
Sections of shore now chiefly undergoing erosion
e
D
E
S. Dennis
S. Yarmouth
W. Dennis
W. Yarmouth
Parkers Neck
W. Harwich
Dennis Port
Harwich Port
S. Harwich
S. Chatham
Chatham
Oyster Pond
Dogfish Bar
Kill Pond Bar
Breakwater
Common Flat
CHATHAM ROADS
Inward Pt
MONOMOY ISLAND
MONOMOY PT.
Stone Horse Shoal
Handkerchief Shoal
Bishop and Clerks
Broken Ground
Senator Shoal
Pt. Gammon
Lewis Bay
OLD TOWER
CUPOLA
TOWER
SPIRES
15'
10'
05'
70°00'

FIGURE 3

of most of the sands on the beaches between Point Gammon and Monomoy Point. Tidal currents may scour the bottom of Nantucket Sound in places but no evidence of sand movement by tidal currents was noted in this area near shore. Before the construction of the groins and jetties the whole length of the shore between these two Points was contributing some material to the beaches. The available sources of new materials at the present time have been diminished where sections of the beach have been widened by groins and jetties. Erosion is now active on the east sides of some of the groins, on the east sides of the jetties, and along sections of the shore that are without either groins or jetties.

The chief sources of beach materials are indicated on plate 3, and representative geologic sections of these areas are shown in plate 2. In general wave-cut cliffs and constructional beaches are readily recognized in the field, so that the particular section of the shoreline that is undergoing erosion or deposition is easily delimited by these features. Storm waves attack the wave-cut cliffs at many places between Hyannis and Chatham in places when there are no jetties or groins and on the east sides of such structures.

The amount of material available depends on the height of the sea cliff and the contour of the exposed surface. There is considerable variation in both of these features. The limitations of this investigation did not permit the great amount of detailed measuring that would be necessary to make quantitative determinations of available materials.

The jetties that are not completely filled on one side by sand

permit very little sand to pass around them. At the present time they divide the beach between Point Gammon and Monomoy Point into segments that retain or dispose of most of their own erosional debris independently of adjacent segments. This is causing some alteration in the shape of the shoreline, especially in the vicinity of the jetties.

Although it is outside the scope of this report to deal with engineering structures, the writer takes the liberty of expressing the opinion that the south shore of Cape Cod can be most effectively protected by the use of groins supplemented by sea walls or riprap in the more exposed places. It is obvious that jetties cause the greatest changes and should be avoided where such changes are detrimental. Because the section of the shoreline between Point Gammon and Monomoy Point acts as a unit by collecting and disposing of its own debris of erosion, structures for shoreline or harbor regulation should not be built for part of the section without carefully considering the effect these structures will have on the section as a whole.

## Offshore Bars and Offshore Profiles

No instrumental measurements or borings could be made in the course of this investigation but observations at low die, and trenching and pitting with a shovel, revealed that the wave-cut platform or bench slopes gently seaward from the base of the wave-cut cliff (see sections). The beach deposit on the wave-cut platform, except

where the beach has been built up by jetties or groins, generally ranges from a few inches to three feet in thickness (see sections). The beach sands are gray, streaked in many places by black or reddish layers of heavy minerals. The glacial sands, on the other hand, which are still undisturbed and which in many places constitute the wave-cut platform, are buff to yellowish-brown. This color is an iron oxide stain caused by prolonged weathering of the outwash sands and gravels that occurred at a time when the sea level was lower. The stain is most intense near the surface of the outwash deposit and diminishes downward. The maximum depth of such weathering is not known but in places it persists at least to a depth of 25 feet below the top of the outwash deposit.

Seaward from the edge of the beach the wave-cut bench is covered by a thin veneer of pebbles, cobbles, sand, and irregularly shaped and distributed sand bars. The outwash sands contain enough gravel to account for the pebble and cobble veneer beyond the beach. Moreover, the pebbles and cobbles are still subangular and of varied types, analogous to the cobbles and pebbles in the glacial deposits.

Sandbars are exposed at low tide in places for several hundred feet offshore. Airplane photographs show that these bars are developed at numerous places all along the shore. An impressive group of bars is located on the east side of Point Gammon opposite the low, narrow section of the Point. These bars are roughly parallel to the shore and are spaced at about equal distances, whereas in other places the bars are irregular. The sand composing the bars appear to have been trapped in the lee of the Point and protected from re-

moval by waves from the southwest. This portion of the shoreline is exposed to southeast storm waves, which probably formed the bars.

## Stability of Sea Level

There is much disagreement concerning the stability of sea level in recent times along the Atlantic Coast. Some authorities believe that the rate of upward shift of sea level relative to the land in eastern Massachusetts is now about two feet per century. J.W.Goldthwait(2) refutes this on the basis of recent investigations and maintains that in the vicinity of Marblehead, Massachusetts, there is no evidence of a change in the position of sea level in the past 130 years.

Woodworth and Wigglesworth(4) state that they have seen no indications of higher stand of the sea in post-glacial time on Nantucket, Marthas Vineyard, or Cape Cod. The writer concurs in this statement as regards Cape Cod. Abandoned wave-cut cliffs are indeed common, but they have been abandoned because of the construction of beaches or bars in front of them and not because of a shift in sea level. A glacial lake may have existed in the southern end of Cape Cod Bay, between the retreating end of the ice lobe and the moraine along the north side of the Cape. Any raised beaches found along the Bay on the north side of Cape Cod may be related to such a lake and not to a former stand of sea level.

Lower stands of sea level are generally more difficult to detect than higher stands. During this study no evidence was noted

of a recent lower stand of sea level. W. F. Jones, however, maintains that sea level has been lower on Nantucket within recent time and his evidence has not yet been published.

The estuaries and the submerged tree stumps and peat provide definite proof that sea level has risen relative to the land since the last glaciation. A submerged peat bog from which logs and stumps were obtained was encountered during recent dredging at the mouth of Witchmere Harbor. The bog is at a depth of about 6 feet below low-tide level and at a distance of about 2,500 feet from the present shore. A section of a log dredged from the bog was identified as swamp white cedar by Dr. W. C. Darrah, paleobotanist at Harvard University. Darrah estimated that the log might be anywhere from 500 to 1,000 years old.

D. W. Johnson(3) concluded from his studies of Nantasket Beach, Cape Cod, and other sections of the New England shoreline, that sea level reached its present position and submergence ceased a thousand to several thousand years ago. He believes that sea level along the New England States has fluctuated very little since that time. It is evident that if sea level is changing on Cape Cod at the present time it is too slow to require consideration in planning shoreline structures.

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